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STABILIZATION OF LAND SLOPES IN SOUTHEASTERN OHIO

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OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER
WOOSTER, OHIO

CONTENTS

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ON THE COVER: Terrace failure at the Eastern Ohio Resource Development Center, May 1973.

ACKNOWLEDGMENTS

The author acknowledges the assistance of Charles Boyles, farm manager at EORDC, for help with the installations; R. B. Curry, K. R. Everett, G. F. Hall, and P. Sutton for advice during the investigation and critical review of the manuscript; B. Beardmore, R. Brehm, G. Hartzell, and D. E. Kopcak for technical assistance; and technicians and members of the farm crew who helped in many ways during the period of investigation.

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Stabilization of Land Slopes in Southeastern Ohio

G. O. SCHWAB[1]

INTRODUCTION

About 3 million acres of land in Ohio, mostly in the southeast, are affected by landslides. As demands for cropland increase, some of this land is being cleared of timber for pasture or agricultural crops. Clearing generally intensifies the slippage problem. Soil movement in this area has produced broad irregular slopes with hummocks and depressions, some with springs and standing water. Slides produce a soil surface which is so irregular that field equipment for tillage, liming, fertilizing, and mowing cannot operate. Fence posts and utility poles are tilted down slope by soil creep. Fields are often too soft for machinery operation during the wet seasons. In some cases soil movement changes the natural drainage pattern as well as damages constructed channels. Buildings and roads are often damaged by slides. Other nonagricultural damages include misalignment and breakage of pipe lines and disruption of highway and railroad traffic.

Landslide problems can be solved in three ways: 1) by avoiding the area entirely, 2) by increasing the resistance of the soil to movement, and 3) by decreasing the forces causing movement (entirely gravitational). In highway and building construction, poor sites can often be avoided, but usually cannot be on agricultural land. Subsurface drainage is one of the principal means of increasing the sliding resistance of soil since removing the water increases the shear strength. Drainage also reduces the force causing movement by decreasing the soil bulk density. This force can also be reduced by decreasing the height of fill or the degree of slope. Vegetation, especially trees, will decrease soil moisture and their roots will increase resistance to soil movement.

Engineering practices that can be justified for highway and building construction are normally too expensive for agricultural land. The identification of potential slide areas is difficult by simple soil tests, from soil maps, from aerial photographs, and from topographic or landscape features. The development of slide areas is often a slow and somewhat aperiodic process. Slopes that have been stable for years may suddenly begin to move and slide, especially after periods of high prolonged rainfall.

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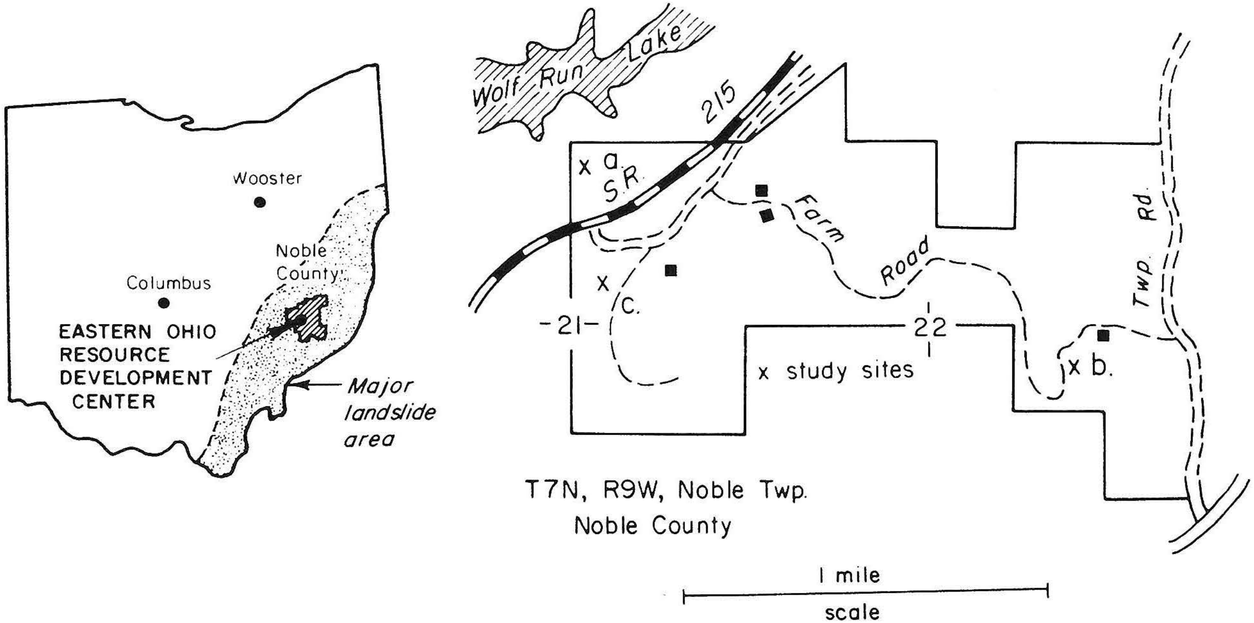


FIG. 1.—Location of major landslide areas in southeastern Ohio and research sites at the Eastern Ohio Resource Development Center (EORDC): a) south slope drainage, b) east slope drainage, and c) bench terrace sites.

The purpose of this study was to evaluate structural measures that would stabilize sloping land in southeastern Ohio and make it more suitable for crop production. A system of parallel subsurface drains was installed in two field sites and a bench terrace was constructed with or without subdrains to evaluate its stability. The flat area of a bench terrace could provide land for growing field and horticultural crops or for constructing a building. As a part of this project, a theoretical study was carried out to evaluate water table levels between parallel subsurface drains on sloping land. This study was reported by Chauhan *et al.* (3).

RELATED STUDIES

Landslides are common in many areas of the United States. Eckel (6) reported on a survey conducted by the Highway Research Board which indicated that landsliding is an important problem in at least 20 states. Most studies have been related to slides in connection with highway and railroad construction and/or strip mine spoil banks. Aerial photographs are being used increasingly to locate slides. Studies relating to the control or correction of landslides have been made by Eckel (6), Cleaves (4), Hennes *et al.* (10), and many other investigators whose reports are summarized by Hoffman *et al.* (11).

Several studies have been made in southeastern Ohio, primarily in the Conemaugh and Monongahelia formations (series). These rock units are of Pennsylvanian age. According to Condit (5), the Conemaugh formation in Ohio crops out in a 10- to 20-mile wide band from Lawrence County to Columbiana County and varies in thickness from 355 to nearly 500 feet. This formation is within the major landslide area in southeastern Ohio (Fig. 1). Further description is given by Everett *et al.* (7), Smith (18), and Fisher *et al.* (8). Fisher *et al.* (8) investigated 87 slides in southeastern Ohio and found that 89% were rotational slumps and 11% earthflows. Red shales were predominant in the unstable zones. These are composed largely of minerals belonging to a clay mica group, illite, which is deficient in bonding by cations of potassium. When the potassium was replenished, the shales were markedly strengthened. Fisher *et al.* (8) found a relationship between landslide frequency and geological stratigraphic sequences, and Hooper (12) concluded that there was little relationship between residual strength and clay mineralogy. Savage (16) studied the nature and type of soil movement in Ohio. Some county soil survey reports also give such information.

Everett *et al.* (7) and Hooper (12) investigated the soils at the Eastern Ohio Resource Development Center (EORDC) by digging deep trenches normal to the slope. One location was within 150 feet of the field site at (b) shown in Fig. 1. Other sites were close to the bench terrace at (c). Everett *et al.* (7) measured the downslope soil movement with steel pipes in relation to base points set in concrete to a depth of 4 to 6 feet. For a 4-year period (1967-71) the movement was 0.45 and 1.14 feet/year near sites (b) and (c), respectively. Movement was multidirectional which produced a hummock and depression or lobate microtopography. These slopes are comprised of about the upper 140 feet of shales, siltstones, and thin limestones of the Conemaugh formation and the lower 100 feet of the Monongahelia sandstones and shales. Hooper (12) reported that at site (b) the soils were composed of mixed-lattice clays (interstratified montmorillonite, vermiculite, and mica) that included both expansive and nonexpansive minerals. Both studies showed that the residual shearing strength of the soil was low, probably because of the high clay content and weathered clay minerals. The residual strength is that remaining after the initial or later series of movements have occurred.

A study by Noble (14) concluded that subsurface drainage is a simple and effective method of stabilizing slopes where there is soil water to remove, even in supposedly low permeability formations. Hooper (12) found that the residual shear strength of unsaturated samples from shear planes was twice that of saturated samples.

For specific soil conditions, such as homogeneous soil and well-defined impermeable layers, a number of experimental and analytical solutions of sloping land drainage problem have been developed. For homogeneous soil, Bouwer (2) found essentially no difference between the flow from drains on the contour or from those up and down the slope for relatively flat slopes (5-10%). However, because of the possibility of intercepting permeable layers and of catching surface water, he recommended that drains be placed nearly on the contour. A steady-state analytical solution for sloping land was developed by Schmid and Luthin (17). For falling water tables, Chauhan *et al.* (3) developed satisfactory analytical and computer solutions.

Evaluation of flow in heterogeneous soils is much more complicated. Nelson (13) obtained a solution by transforming a heterogeneous soil to an equivalent homogeneous one. Thiel and Bornstein (19) used an electric analog to locate drains in a sloping fragipan soil. These investigations show that reasonable analytical or model solutions are available but that the major problem is one of evaluating the soil hydraulic conductivity and drainable porosity.

Several studies have shown that clearing of trees and brush is a factor in causing increased soil movement. In California, Rice *et al.* (15)

reported that occurrence of slips was inversely related to the size and density of vegetation. Wu (20) found that in Alaska the shear strength of the soil increased as the amount of roots increased. Gray (9) reported that forest cover reduced soil moisture and increased the strength of the soil mantle.

FIELD SITES

Field studies were started in 1968 on the EORDC near Caldwell in Noble Township in Noble County. Location of the sites is shown in Fig. 1. Soils were generally more than 60-70% clay. They are further described by Everett *et al.* (7) and Hooper (12) for sites shown in Figs. 1b and 1c. The soils are typical of the upper Conemaugh and lower Monongahelia geologic formations in which landslides and mass movement are continually occurring (Fig. 1).

South and East Slope Drainage Sites

About 2100 feet of 2-inch diameter corrugated plastic drain tubing were installed on grades up to 6% at the two sites in the fall of 1972 (Fig. 2). Spacing between drains varied from about 20 to 45 feet. The drains were installed with a mole plow at a depth of about 2 feet on land slopes averaging 15% which showed evidence of active soil movement. Twenty-two observation markers, described in Fig. 3, were located near the drains as shown in Fig. 2. A 1⅞-inch diameter rigid probe was placed in the tubing prior to filling the hole with sand to assure a straight tube. Distances between markers and straightness of the tubing (probe measurements) were determined to detect relative soil movement. Elevation of the markers was taken every 1 or 2 years.

Bench Terrace Site

Prior to construction of the bench terrace shown in Figs. 4 and 5, water table and piezometer measurements were taken in 1968 and 1969. The water table reached the surface in nearly every pipe at least once in both years. As expected, the water table fluctuated with rainfall. Piezometer measurements at nine locations showed that water movement was all downward. Soil samples taken in March 1968 showed considerable variation in moisture content and in bulk soil density. Laboratory hydraulic conductivity tests on 3-inch diameter cores taken at about tile depth gave values from nearly zero to about 20 inches/hour.

The bench terrace was constructed in the late fall of 1969 on an original slope of 19%. As shown in Figs. 4 and 5, pipe drains were installed in undisturbed soil at a spacing of 30 feet in the south half of the terrace. Horizontal distances between markers and elevations were recorded every 1 or 2 years to detect relative soil movement.

During construction of the terrace, an attempt was made to remove unstable soil prior to placement of the fill. Slickensides (shear planes)

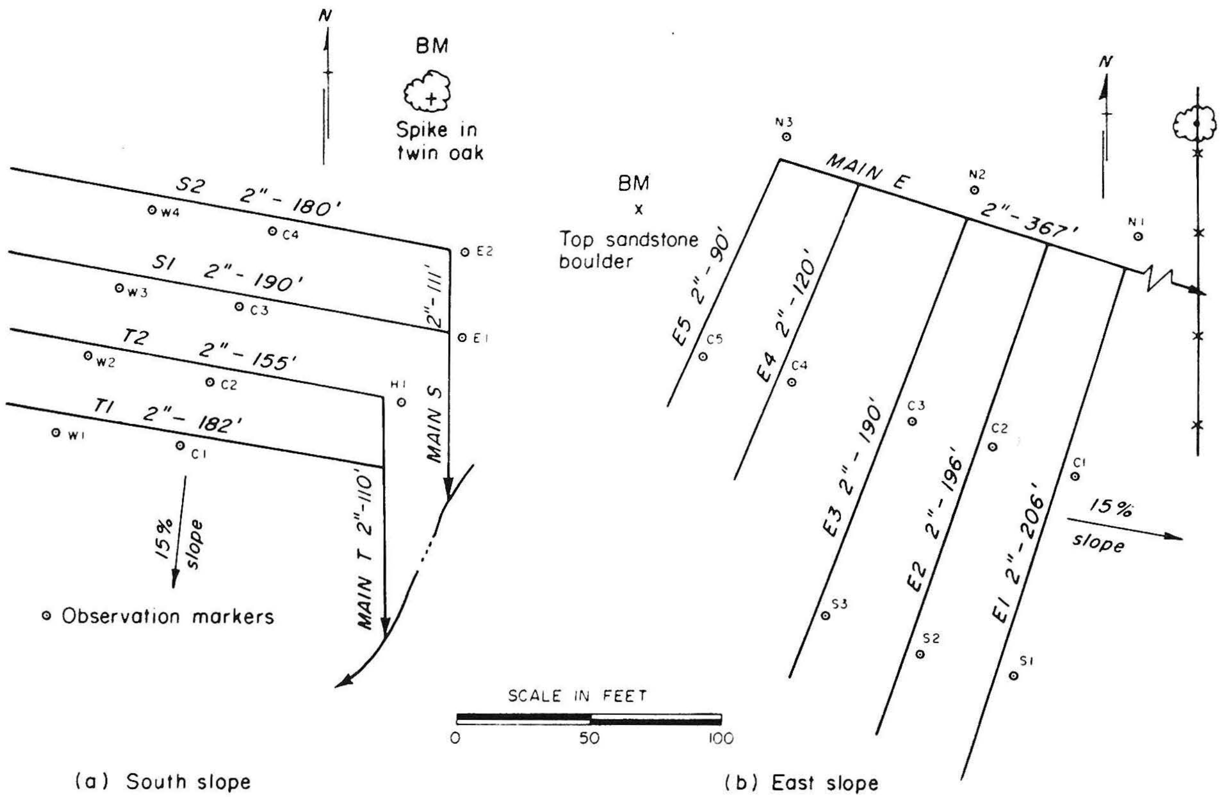
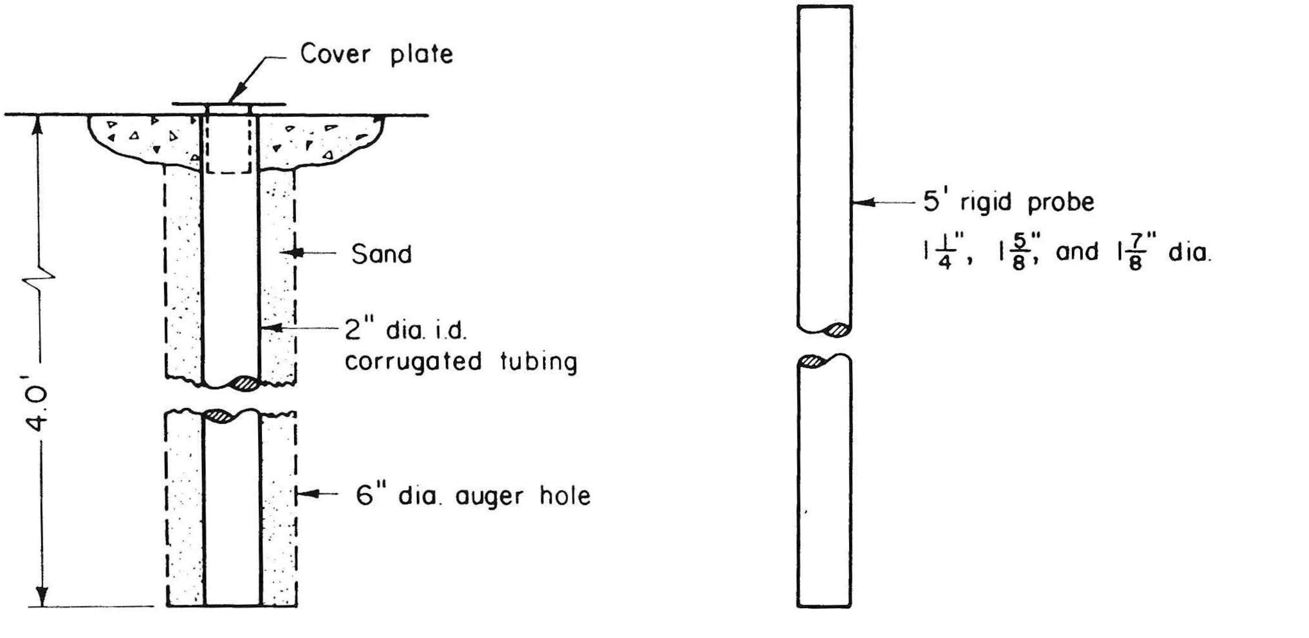


FIG. 2.—Layout of the (a) south slope and the (b) east slope drainage sites.



(a) Observation marker (b) Alignment probe

FIG. 3.—Detail of soil movement observation markers installed at sites (a) and (b).

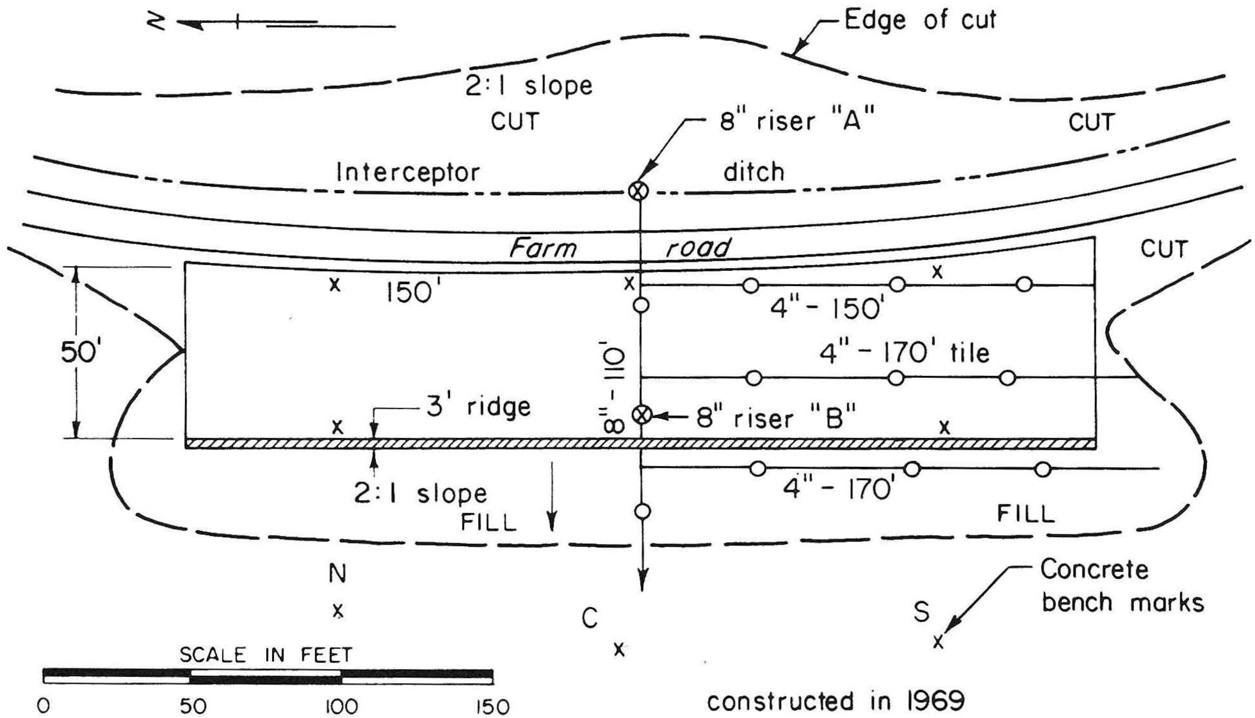


FIG. 4.—Plan view of bench terrace as built.

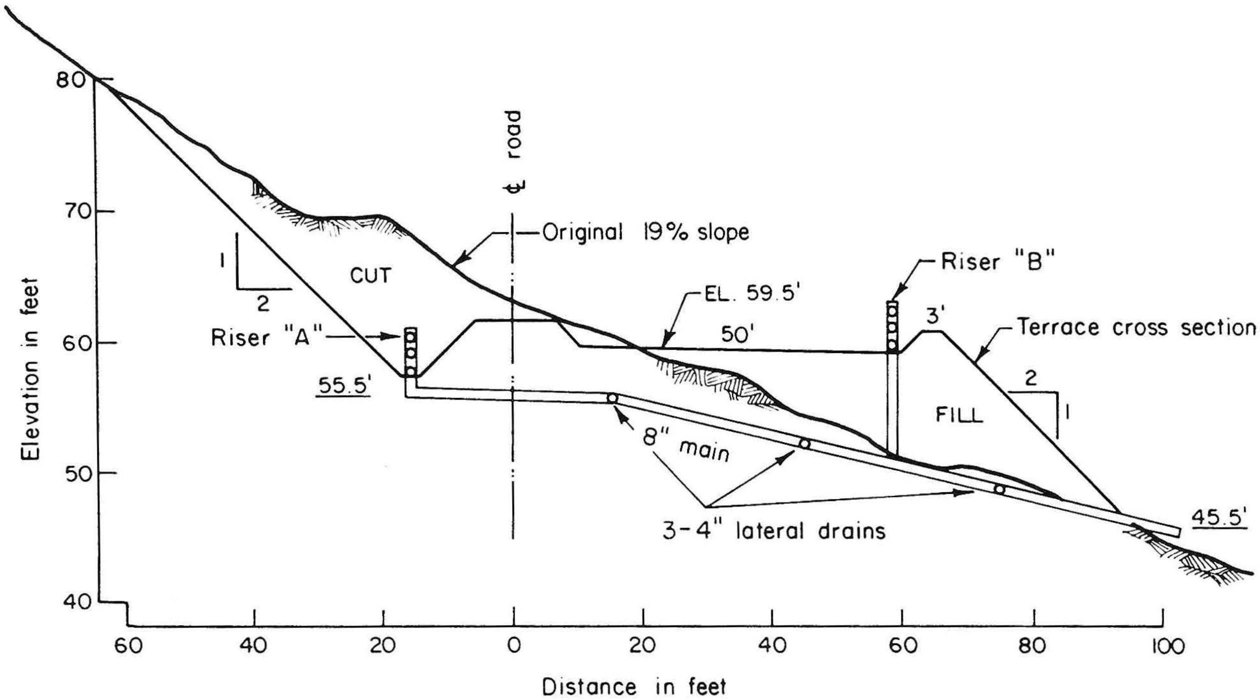


FIG. 5.—Cross section of bench terrace through center (C) section.

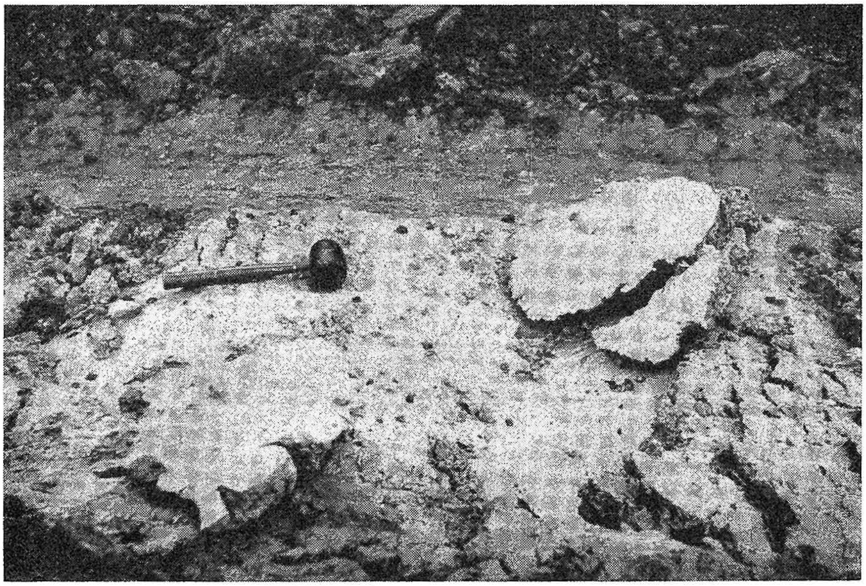


FIG. 6.—Example of "slickenslide" observed during construction of the bench terrace.

were observed during construction as shown in Fig. 6. The soil slid on these surfaces when the soil was excavated with a scraper. These slip planes were less than one-eighth of an inch in thickness. Hooper (12) also observed these slickenside planes in the trench wall of his excavations. These were more numerous near the lobate terrace landforms (mounds), but were nearly continuous down the slope at depths from 3 to 12 feet extending 30 to 40 feet laterally from the trench. These planes were found at the boundary between two dissimilar clayey soils. The American Geological Institute (1) defines a slickenside as a polished and smoothly striated surface that results from friction along a fault plane

SOIL MOVEMENT OBSERVATIONS

Measurements include those taken at the two subsurface drained sites and at the bench terrace before and after failure.

South and East Slope Drainage Sites

Elevation and distances between markers as well as movements of the concrete markers are shown in Tables 1 and 2. Measurements were taken soon after installation, after 6 years, and at intermediate times (latter not included in this report).

At the south site (Fig. 2a), the measurements shown in Table 1 indicate little if any significant movement. A small failure rim was evident before the drains were installed and 6 years later it was still there, but the slope appeared to be stabilized. The greatest misalignment of the vertical markers and horizontal movement was along the upper edge of the drained area. It was not possible to tell from the horizontal measurements which of two adjacent markers had moved. Movement less than 0.1 ft should be ignored as this is probably within the error of measurement. Elevation changes were 0.1 ft or less and these were also within the measurement error.

TABLE 1.—Movement of Observation Markers on South Slope, 6 Years After Installation.

Marker No.	Elevation Change in Feet	Vertical Misalignment in Inches to Depths of 1 ft	2 ft	3 ft	4 ft	Inclination of Marker from Vertical: Degrees	Direction
W1	+0.02				0	1	Upslope
W2	—0.10				0	4	Downslope
W3	lost 1977						
W4	—0.10	1/8			3/4	3	Downslope
C1	—0.04	1/8			3/8	2	Downslope
C2	—0.10				0	2	Downslope
C3	—0.10	1/8			3/8	3	Downslope
C4	—0.06	1/8			3/8	5	Downslope
E1	+0.02				0	2	Downslope
E2	—0.04	1/4			3/8	3	Downslope
H1	—0.01	1/4			3/8	8	Downslope

From	To	General Direction	Change in Horizontal Distance in Feet
E1	E2	Downslope	—0.09
C1	C2	Downslope	+0.10
C2	C3	Downslope	+0.07
C3	C4	Downslope	+0.24
W1	W2	Downslope	—0.11
W2	W4	Downslope	+0.15
		Av. Downslope	+0.06
E1	C3	Cross slope	—0.12
E2	C4	Cross slope	+0.02
H1	C2	Cross slope	—0.05
C1	W1	Cross slope	+0.21
C2	W2	Cross slope	+0.07
C3	W3	Cross slope	lost 1977
C4	W4	Cross slope	+0.02
		Av. Cross slope	+0.02

At the east slope, elevations shown in Table 2 indicate little if any elevation change. Vertical misalignment and horizontal distance changes between markers showed considerably more change than at the south slope site. More than half of the markers were misaligned more than three-fourths inch at a depth of 4 feet. Some sliding of the N2 marker to the south appears to have occurred. The east central portion of the drained area was a swampy filled-in depression prior to drainage. By 1979, swampgrass and water weeds were largely replaced by more desirable grasses. The drains greatly improved the area and little if any water was found on the surface compared to other undrained sites nearby.

TABLE 2.—Movement of Observation Markers on East Slope, 6 Years After Installation.

Marker No.	Elevation Change in Feet	Vertical Misalignment in Inches to Depths of				Inclination of Marker from Vertical	
		1 ft	2 ft	3 ft	4 ft	Degrees	Direction
N1	+0.13	1/4	3/4			15	Downslope
N2	—0.06	1/4			3/4 +	5	Downslope
N3	—0.06	1/2 *			3/4 +	2	Upslope
C1	lost 1977				0†		
C2	—0.06	1/4			3/4 +	2	Downslope
C3	+0.10	3/8		3/4		12	Downslope
C4	lost 1977				0†		
C5	lost 1977				0†		
S1	+0.04	3/4 *		7/8 *		10	Downslope
S2	+0.12	3/4 *		7/8 *		7	Upslope
S3	+0.06				3/8	1	Upslope

From	To	General Direction	Change in Horizontal Distance in Feet
N1	N2	Downslope	—0.37
N2	N3	Downslope	+0.04
C2	C3	Downslope	—0.13
S1	S2	Downslope	+0.48
S2	S3	Downslope	+0.03
		Av. Downslope	+0.01
N1	S1	Cross slope	+0.05
C2	S2	Cross slope	—0.01
N2	C3	Cross slope	0.00
C3	S3	Cross slope	—0.04
N3	BM	Cross slope	—0.20
		Av. Cross slope	—0.04

*Estimated from closest measurement.
†Measured after 2 years.

Bench Terrace Site

The bench terrace failed about March 20, 1973, 3 years after construction. Small cracks were noted near the outer rim in the Spring of 1972. Failure occurred mostly as a rotational slide with deformed units within the slide as shown in Figs. 7 and 8. Eckel (6) describes such a slide as a Class IIb type. The upper surface of failure typically has a back slope toward the uphill side. The tipping of the upper concrete marker in Fig. 7 showed evidence of slide movement near the surface which is not typical of a rotational slide. The lower section of the slide moved down slope with an increase in elevation of the surface, which is typical of a rotational slide. Cross sections were taken in June 1973, about 3 months after the initial failure, and resurveyed about every 2 years thereafter. The cross sections taken in 1975 and 1977 are not shown in Figs. 7 and 8, but they would plot somewhere between the (6/73) and (8/79) lines. The top of the upper concrete marker in Fig. 7 moved horizontally downhill 13.7 ft. and dropped 4.8 ft. in elevation compared to the markers next to the road, which showed no movement. Figure 9 is a photo of the marker and slide area. The upper marker in Fig. 8 in the drained section moved only 0.3 ft downslope and only 0.18 ft lower in elevation during the 9-year period.

The upper edge of the slide called the failure rim is shown in Fig. 10. Figure 11 shows the failure rim with the drained section in the foreground. The average distance of movement at 2-year intervals is shown in Table 3. This distance was arbitrarily measured from the outer edge of the original terrace ridge. The distances for the undrained section were taken between the N and the C lines, and those for the drained section were taken between the C and the S lines. The drains appeared to reduce the initial slide area (6/73), but movement of the failure rim for the drained and the undrained sections was nearly the same thereafter. The initial failure disrupted the main 8-inch drain line. The lower 50 feet were replaced in September 1973. By about 1977, the outlet pipe was again covered up by the slide and drainage was again impaired.

Precipitations 1, 6, and 12 months prior to dates of measurement are tabulated in Table 3 to see if these can be related to slide movement. One month prior to initial failure, precipitation was slightly below normal, but for the prior 6- and 12-month periods it was less than 10% above normal. Average temperatures in March 1973 were about 9° F above normal and in February about 2° F below normal. It thus appears that there was no unusual rainfall that would have triggered the slide; however, the higher temperatures may have accelerated thawing. The average rate of rim failure for the 1973-75 period was more than

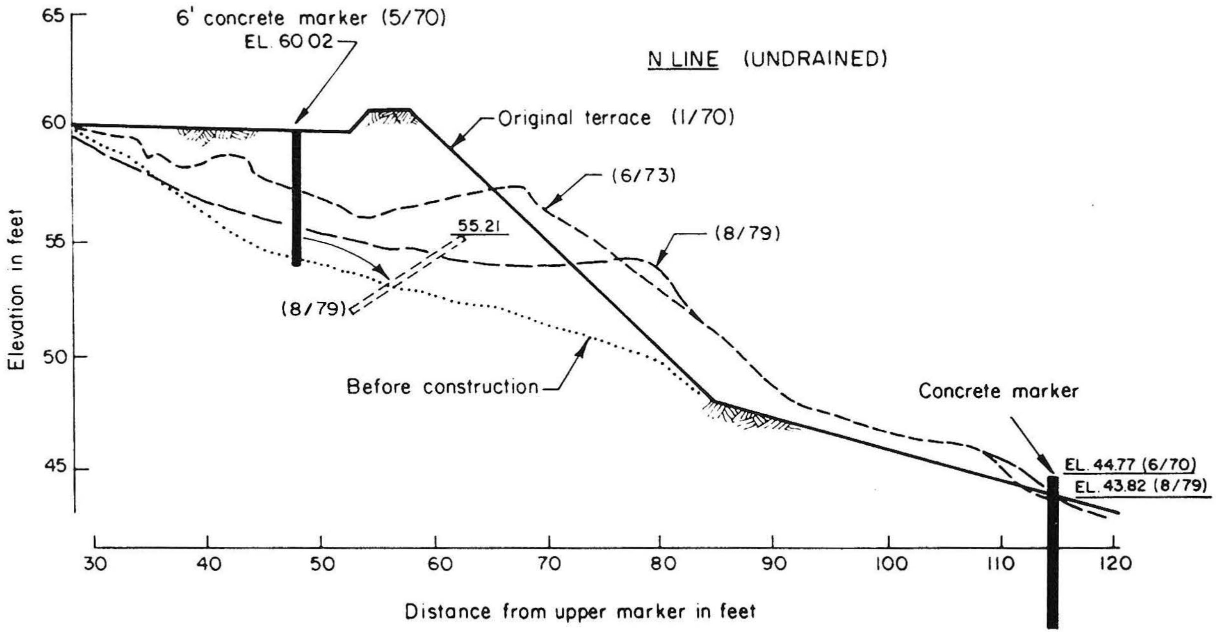


FIG. 7.—Cross section of the bench terrace through undrained end (N) before and after failure.

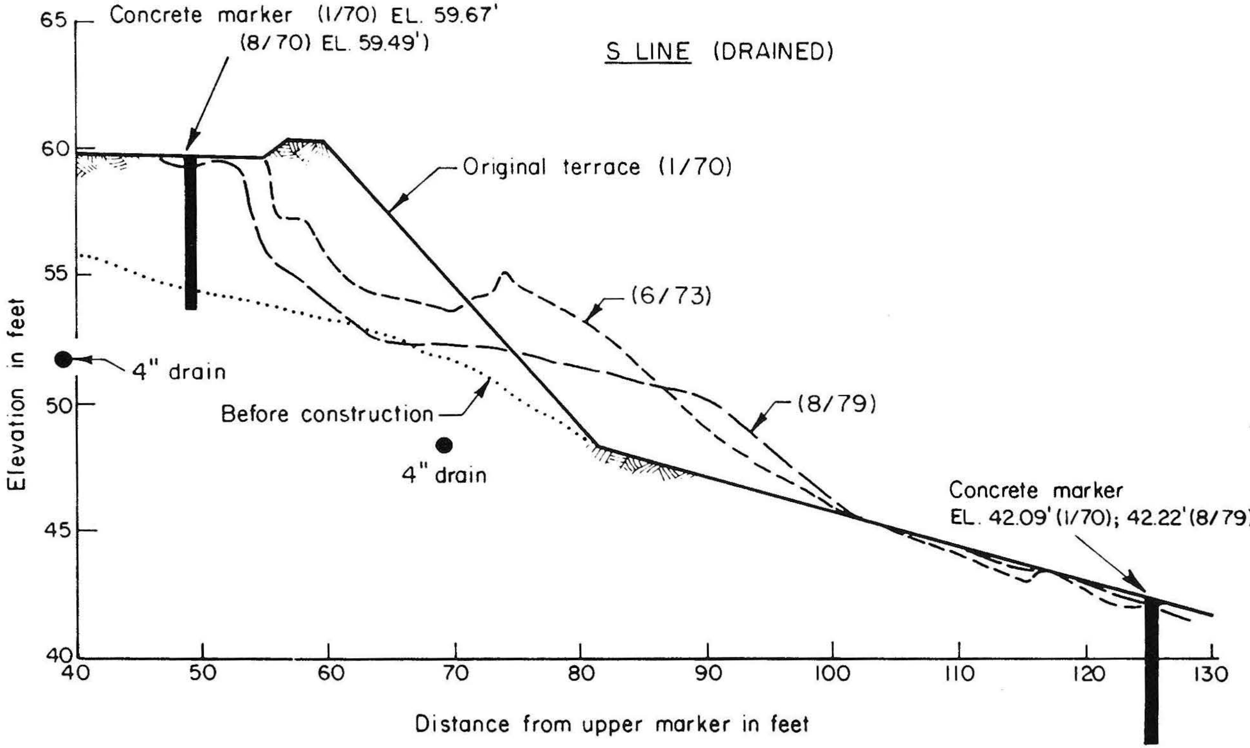


FIG. 8.—Cross section of bench terrace through drained end (S) before and after failure.

FIG. 9.—Failure section of bench terrace in 1979 showing concrete marker on N line near outer ridge.

TABLE 3.—Average Distance of Movement of Failure Rim on Bench Terrace.

Date of Measurement	Precipitation in Inches Prior to Date			Distance of Movement of Failure Rim in Feet†	
	1 mo	6 mo	12 mo‡	Undrained (North)	Drained (South)
March 20, 1973*	2.1	21.3	39.7	0	0
June 5, 1973	5.4	22.2	43.8	18	2
June 6, 1975	6.1	22.4	50.5	25	9
May 18, 1977	1.8	9.7	27.1	28	12
August 29, 1979	16.7	30.8	53.2	32	17

*Initial failure date (approximate).

†Average distance measured from outer edge of original terrace ridge (see Fig. 10). Undrained from N to C lines; drained from C to S lines.

‡Average annual precipitation about 38.2 inches.

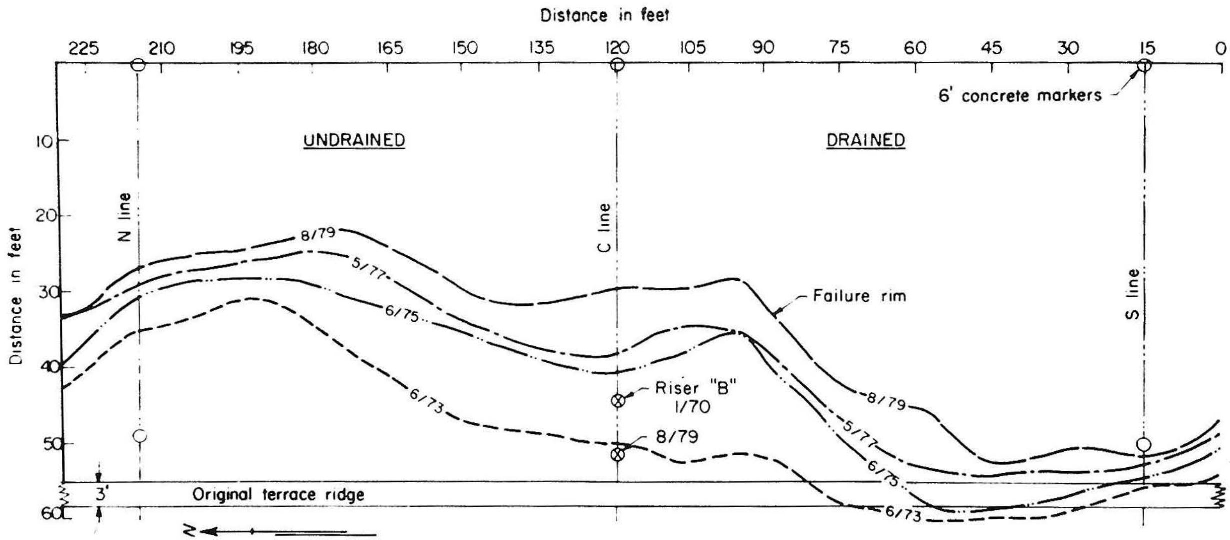


FIG. 10.—Top view of bench terrace showing edge of failure rim from 1973 to 1979

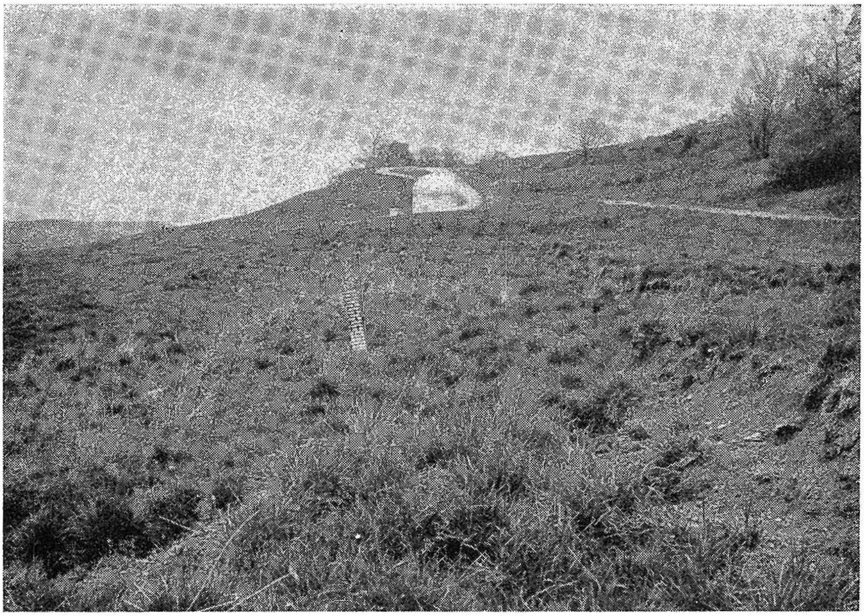


FIG. 11.—Failure rim of bench terrace in 1979 looking north.

double that for the 1975-77 period. Since precipitation was much greater for the 1973-75 period, it may have contributed to the greater failure rate. Although rainfall was high just prior to the 1979 measurement, it did not appear to increase failure rate, probably because most of it came in August when evapotranspiration was high and soil moisture was low. Precipitation is obviously an important factor which contributes to failure. Movement appears to continue gradually year by year, but it seems to be influenced by a combination of factors difficult to relate to soil movement.

DISCUSSION

Stabilization of steep slopes in southeastern Ohio may not be economically justified, especially for pasture land. Steep land will continue to move until a stable slope is reached. Mechanically reducing the slope or installing subsurface drains and reshaping may be economically feasible for construction sites or for intensive land use. For pasture land, the best solution may be to do nothing. Minimum cost measures, such as diversion ditches to intercept surface runoff, surface drainage of depressions, subsurface drainage of springs or extremely wet areas, and other measures that the farmer can do with his own equipment can probably be justified. Small diameter plastic tubing pulled in with a mole plow was found to have a stabilizing influence for the two sites studied. For drain spacings of 20 to 40 feet, the benefit-cost ratio is probably borderline. Further research is needed, especially to identify drainable sites and to pinpoint where drains should be placed.

The results of this study should be used with caution because the field sites were not replicated. Sufficient tests were not made to evaluate the drains under the bench terrace. The wide variability of the soil both horizontally and vertically precluded the time and cost of making such tests. Although construction techniques in making the terrace were believed to have been satisfactory, measurements were insufficient to make an analytical evaluation of the failure. Soil data and tests performed by Hooper (12) and Everett *et al.* (7) may be applicable as they were taken within a short distance of the sites in this study. After failure of the bench terrace, soil movement in the slide area was much more than 0.45 to 1.14 feet/year as measured for the natural slide areas studied by Everett *et al.* (7). Although the two areas are not directly comparable, the studies do show that works of man may increase the land sliding problem. Hopefully, these studies will add to the store of knowledge that may lead to a more satisfactory solution to the landslide problem.

SUMMARY AND CONCLUSIONS

Two field sites were drained with a parallel system of subsurface drains, and a bench terrace was constructed at the EORDC near Caldwell. Observations were made over a period of 9 years to evaluate the effectiveness of the drains for stabilizing sloping land and to evaluate the stability of a bench terrace placed on a 19% slope. The subsurface drains were effective in stabilizing the land and in improving desirable vegetation.

The bench terrace failed 3 years after construction. The progress of the failure and cross sections of the terrace were recorded biannually for 6 years of failure. Pipe drains placed under half of the terrace reduced the slide area of the initial failure, but did not affect the failure rate thereafter. The shear strength of this soil is too low for the use of bench terraces with a 2:1 backslope.

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The State Is the Campus for Agricultural Research and Development

Ohio's major soil types and climatic conditions are represented at the Research Center's 12 locations.

Research is conducted by 15 departments on nearly 7,000 acres at Center headquarters in Wooster, eight branches, Pomerene Forest Laboratory, North Appalachian Experimental Watershed, and The Ohio State University.

Center Headquarters, Wooster, Wayne County: 1953 acres

Eastern Ohio Resource Development Center, Caldwell, Noble County: 2053 acres

Jackson Branch, Jackson, Jackson County: 502 acres

Mahoning County Farm, Canfield: 275 acres

Muck Crops Branch, Willard, Huron County: 15 acres

North Appalachian Experimental Watershed, Coshocton, Coshocton County: 1047 acres (Cooperative with the Science and Education Administration/Agricultural Research, U. S. Dept. of Agriculture)

Northwestern Branch, Hoytville, Wood County: 247 acres

Pomerene Forest Laboratory, Coshocton County: 227 acres

Southern Branch, Ripley, Brown County: 275 acres

Vegetable Crops Branch, Fremont, Sandusky County: 105 acres

Western Branch, South Charleston, Clark County: 428 acres